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A preliminary interpretation of surficial marine geology of central and northern Strait of Georgia, British Columbia

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Abstract: Six acoustic and sedimentary facies have been mapped in the central and northern Strait of Georgia that reflect the late Quaternary development of the region. During the Vashon Stade of the Fraser Glaciation, a Quaternary, preglacial deposit that filled most of the basin was eroded by glacial ice moving south down the strait. Ice-proximal and ice-distal glaciomarine deposition over glacial till occurred during the rapid deglaciation of the strait with development of marine conditions by 12.4 ka BP. Sea level fell during deglaciation from a relative high stand and continued to fall after all ice had left the strait reaching a low stand sometime after 10 ka BP. Holocene deposition within the strait has been dominated by the Fraser River plume and coastal and nearshore processes.

Résumé : Dans le centre et le nord du détroit de Georgia, on a relevé six faciès acoustiques et sédimentaires qui témoignent de l'histoire géologique du Quaternaire supérieur dans cette région. Durant le Stade de Vashon de la Glaciation de Fraser, un dépôt préglaciaire du Quaternaire qui s'étendait à la plus grande partie du bassin a été érodé par la glace s'avancant vers le sud dans le détroit. Il y a eu dépôt de sédiments glaciomarins sur le till à proximité et à distance de la glace pendant la déglaciation rapide du détroit qui a mené à l'apparition de conditions marines il y a 12 400 ans au plus tard. À partir d'une hauteur relativement élevée, le niveau de la mer s'est mis à baisser pendant la déglaciation et cette baisse s'est poursuivie même une fois que toute la glace eut disparue du détroit jusqu'à l'atteinte du niveau le plus bas il y a un peu moins de 10 000 ans. Pendant l'Holocène, la sédimentation dans le détroit a été conditionnée principalement par le panache de sédiments du fleuve Fraser, ainsi que par des processus littoraux et côtiers.

INTRODUCTION

The late Quaternary glacial, postglacial geology, and sea-level history of the central and northern Georgia Depression has been derived primarily from mapping of the coastal lowland surrounding the Strait of Georgia (Fig. 1). The advance and retreat of late Wisconsin ice within the strait has been inferred from extensive coastal mapping (Fyles, 1963; Clague, 1976, 1981, 1994). In order to affirm these interpretations and determine the late Quaternary chronology of development within the central and northern strait, a marine mapping program was initiated in 1996.

Two scientific cruises were conducted to collect a regional (approximately 6 km spacing; Fig. 1) network of geophysical subbottom profiles and 54 sediment cores (Fig. 2) to 1) map the surficial geology of the region, 2) establish a preliminary interpretation of the late Quaternary development of central and northern Strait of Georgia, and 3) identify geological hazards within this region, an area that is being subject to rapid coastal development. The initial results from analyses of these data are presented here and a full interpretation will be published when analyses are complete.

REGIONAL GLACIAL AND SEA-LEVEL HISTORY

During the early stages of the Fraser Glaciation, thick, well sorted sand deposits (Quadra Sand) were deposited in front of, and possibly along the margins of, glaciers moving down the Strait of Georgia (Clague, 1976, 1977, 1994). Ice moving south from the Coast Mountains of the Canadian Cordillera and Vancouver Island progressively coalesced, over rode, and eroded these deposits. This large glacier advanced down the Strait of Georgia to the south end of the Puget Lowland (Waitt and Thorson, 1983), reaching its maximum extent about 17.0 ka BP (Porter and Swanson, 1998). Glacial retreat in the Puget Lowland began as early as 16.9 ka BP (Porter and Swanson, 1998) and possibly as late as 14 ka BP within the Strait of Georgia (Clague, 1981, 1994). Many areas of the strait where ice free as early as 13 ka BP and completely deglaciated at 11.3 ka BP (Clague, 1981, 1994). Glaciomarine and glacial-fluvial sediments (Capilano Sediments) accumulated along the coastal lowlands of the strait during deglaciation and sea-level fall.

At the maximum extent of the Fraser Glaciation, the entire Strait of Georgia region was isostatically depressed with the greatest vertical displacements exceeding 250 m (Clague, 1983). Isostatic uplift accompanied rapid deglaciation at the



Figure 1.

Central and northern Strait of Georgia showing the geophysical survey coverage from two scientific cruises.

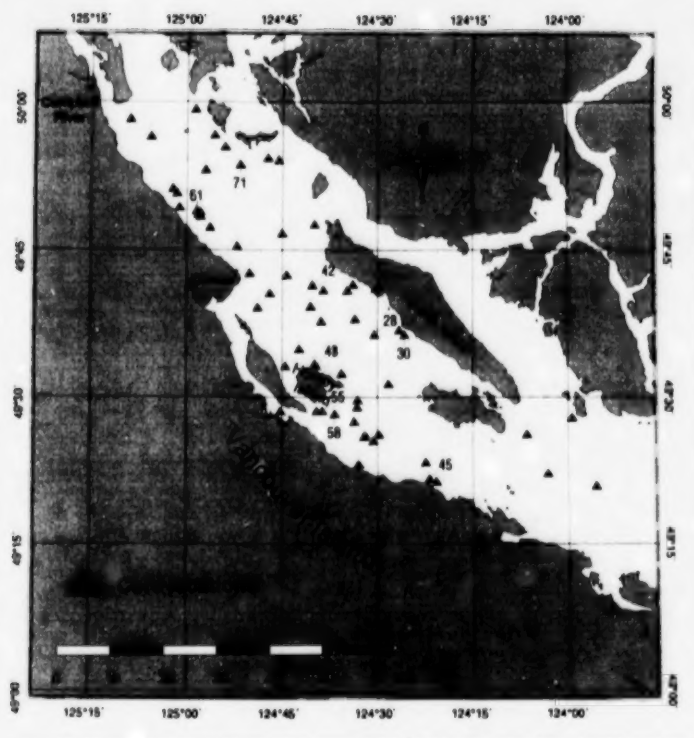
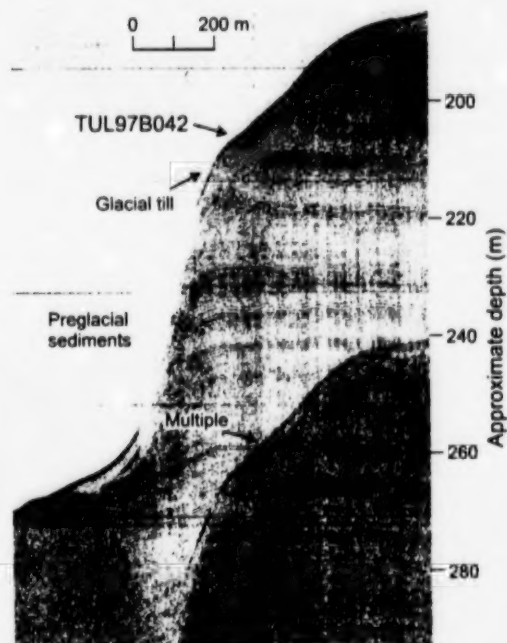
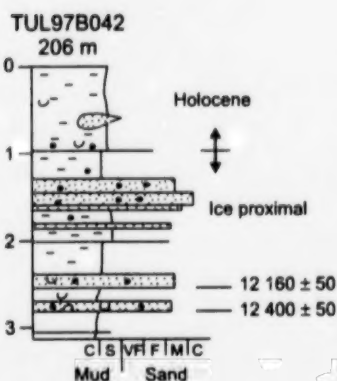


Figure 2.

Distribution of sediment cores collected in the central and northern Strait of Georgia and raised beach sections on Texada Island. Cores with a number designation refer to the last two digits of cores listed in Table 1 and shown in Figures 3–5.

Figure 3.

Huntec™ DTS subbottom profile of stratified preglacial sediments west of Texada Island (Fig. 2). Overlying the thick preglacial sediments is a glacial sequence which is capped by Holocene mud. The sediment core (TUL97B042) only penetrated through to the ice-proximal sediments and some of the Holocene section was lost in core recovery aboard the ship.



C Clay
S Silt
VF Very fine sand
F Fine sand
M Medium sand
C Coarse sand

Gravel
Sand
Silt
Clay
Shells/shell debris

12 160 ± 50 Age (¹⁴C years BP)
206 m Water depth

end of the Pleistocene. The isostatic uplift exceeded eustatic rise resulting in relative sea-level fall of between 50–200 m, depending on locality (Clague, 1994). Sea level fell below its present position between 12 and 10 ka BP reaching its lowest position approximately 9.2 ka BP (Clague et al., 1982; Clague, 1983). A transgression occurred during the early to middle Holocene, due primarily to eustatic rise. Sea level was within a few metres of its present position by about 5 ka BP (Clague et al., 1982).

METHODS

A regional grid of high-resolution HuntectTM DTS subbottom profiles, SimradTM sidescan sonar, and airgun seismic lines were collected during a scientific program on *CCGS Vector* in June 1996 and *CCGS John P. Tully* in August 1997 (Fig. 1). On the 1997 scientific program, 28 vibrocores and 26 piston cores were retrieved from sites selected from initial interpretation of the 1996 geophysical data (Fig. 2). Seven piston cores collected in 1992 from the *CCGS John P. Tully* near the BC Hydro electrical cable corridor were also used in this study (Fig. 2). Cores were split in the laboratory, photographed, and sampled for textural analyses, radiocarbon dating, and foraminiferal, pollen, and diatom analyses. The results of the foraminiferal, pollen, and diatom analyses will be discussed in a future publication.

PRELIMINARY RESULTS

Six Quaternary facies have been identified from the acoustic stratigraphy that overlie bedrock or older Pleistocene deposits. They are 1) stratified preglacial sediments, 2) glacial till, 3) ice proximal deposits, 4) glaciomarine mud, 5) Holocene mud, and 6) Holocene sand and gravel.

Stratified preglacial sediments

Thick (greater than 80 m) well stratified sediments occur over much of western margin of the northern Strait of Georgia and surrounding Texada Island (Fig. 3). These units are generally overlain by a diamicton but there is no evidence of an unconformity. Generally the unit is discontinuous and exists as eroded remnants with slopes in excess of 25°. Clague (1977) suggested that the Georgia Basin should have filled during the nonglacial to glacial transition at the beginning of the Fraser Glaciation based on his mapping and depositional interpretation of the Quadra Sand at margins of the basin. This unit may then represent the marine equivalent of the Quadra Sand as postulated by Clague (1977). At present no cores have been obtained into this unit, limiting our ability to confirm this interpretation at present. The existence of thick unconsolidated sediments at excessive slopes does, however, represent a potential geological hazard in the event of a seismically or otherwise triggered submarine failure and tsunami.

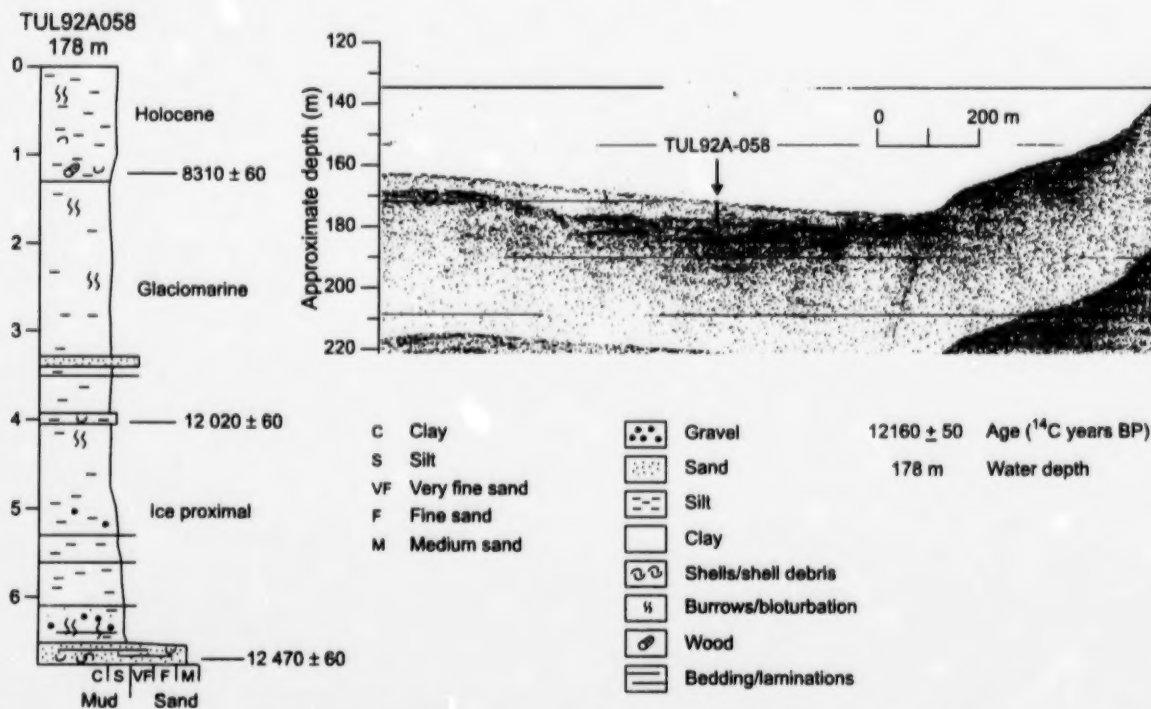


Figure 4. HuntectTM DTS subbottom profile illustrating the late Quaternary stratigraphy of the central Strait of Georgia. A sediment core (TUL92A058) that penetrated to the till boundary shows the transition from ice-proximal sedimentation to the Holocene. Location of the core is shown in Figure 2.

Glacial till

Glacial deposits occur throughout the strait based on the interpretation of seismostratigraphical and sedimentological core data. Glacial till is defined by its uniform unstratified character with a strong surface reflector and high internal backscatter in the subbottom profiles (Fig. 4). Cores recovered within the till units consist of massive, poorly sorted gravelly muddy sands with pebbles to 10 cm. These sedimentological characteristics are consistent in all cores that penetrated till and appear to be very similar to the sandy till of the coastal lowland (Fyles, 1963).

Ice-proximal deposits

Overlying glacial till is a generally thin unit (less than 10 m) that has a complex stratification with discontinuous and broken reflectors in the acoustic records (Fig. 3, 4). In core, these sediments are primarily laminated grey clay interbedded with well sorted sand and sometimes thin silt laminations (Fig. 3, 4). The thickness and spacing of the sand laminations is very irregular. Ice-rafted pebbles also occur randomly within this facies. This unit is interpreted to represent ice-proximal sedimentation similar to that on the northwestern Canadian continental shelf (Barrie and Conway, 1999) and in Tarr Inlet of Glacier Bay, Alaska (Cai et al., 1997). This unit dates consistently around 12.4 ka BP from four different cores covering most of the northern Strait (Table 1).

Glaciomarine mud

Glaciomarine mud overlies the ice-proximal sediments and, in a few areas, the glacial till. It consists of weakly reflective, well stratified sediments that contain, in decreasing order,

clay (45%), silt (35%), sand (15%), and ice-rafted gravel (5%) (Fig. 4). The mud layers are usually bioturbated. This facies compares closely with the ice-distal glaciomarine muds (unit A) found in Dixon Entrance north of the Queen Charlotte Islands (Barrie and Conway, 1999). Three dates from shells in this unit vary from 12 020–11 270 years BP (Table 1), consistent with the interpreted completion of deglaciation of the area (Clague, 1981).

Holocene mud

Below 140 m water depth, a thick (20–60 m), nonreflective unit occurs which consists of bioturbated mud dominated by clay with generally less than 5% sand. The unit is thickest and most extensive towards the south where the influence of sedimentation from the Fraser River plume is greatest.

Holocene sand and gravel

In shallower waters (less than approximately 80 m water depth), particularly along eastern Vancouver Island and the northern Gulf Islands, generally thin (less than 15 m) deposits of highly reflective and stratified sediments occur. These sand and gravel units vary in texture from locality to locality and coarsen in areas of high tidal currents, particularly towards Discovery Channel near Campbell River where moderately sorted gravels occur. Sediment is derived from rivers along Vancouver Island and coastal erosion of thick unconsolidated Quaternary bluffs on Vancouver Island and the northern Gulf Islands (Clague and Bornhold, 1980).

Table 1. Radiocarbon dates obtained from cores recovered in central and northern Strait of Georgia. Shell dates are corrected for an 800 year reservoir effect based on the corrections of Southon et al. (1990). Lithological units (G - glaciomarine, H - Holocene, IP - ice proximal, RB - raised beach) are discussed in the text and the core locations are shown in Figure 2.

Lab #	Core	Water depth (m)	Sample depth (cm)	Dated specimen	Radiocarbon date	Lithological unit
33804	T92A055	103	60	<i>Yoldia amygdalea</i>	12 100 ± 60	G
33933	T92A058	178	122	wood	9110 ± 60	H
33802	T92A058	178	402	<i>Rhabdus rectus</i>	12 020 ± 60	G
33803	T92A058	178	670	<i>Nuculana fossa</i>	12 470 ± 60	IP
51003	T97B028	231	55	<i>Yoldia thraciaeformis</i>	12 380 ± 50	IP
51004	T97B030	170	19	<i>Yoldia martyria</i>	12 340 ± 50	IP
50333	T97B042	206	280	shell	12 400 ± 50	IP
51006	T97B042	206	252	<i>Yoldia thraciaeformis</i>	12 160 ± 50	IP
51007	T97B045	28	132	<i>Macoma lipara</i>	10 130 ± 50	H
51008	T97B048	24	59	<i>Compsomyx subdiaphana</i>	9990 ± 60	H
52959	T97B048	24	106	<i>Panomya arctica</i>	11 120 ± 50	G?
52086	T97B061	104	77	<i>Nuculana fossa</i>	11 270 ± 50	G
52091	T97B071	179	118	<i>Macoma lipara</i>	12 310 ± 60	G
52955	GBP9803	+81 elevation		<i>Saxidomus giganteus</i>	11 940 ± 50	RB
54057	GPB9803	+82 elevation		<i>Saxidomus giganteus</i>	11 250 ± 50	RB
52956	GPB9804	+80 elevation		<i>Saxidomus giganteus</i>	11 740 ± 60	RB

*Radiocarbon analysis undertaken at the Centre for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory.

SEA-LEVEL CHANGE

Preliminary data support the interpretation of Clague (1983) of a high stand of sea level at the end of the late Wisconsin glaciation followed by a relative sea-level fall to below present levels. On Texada Island, in the centre of the Strait of Georgia, a raised beach deposit located at 80 m above present sea level dates between 11 940 and 11 250 years BP (Fig. 5a). This extensive deposit (2 km in length) formed in open marine conditions where an ample supply of sand was available (Quadra Sand). These dates fit the general sea-level curve for Comox-Nanaimo region (Clague et al., 1982).

From a preliminary analysis of the seabed cores, no evidence was found of a sea-level low stand. One core (core TUL97B048; Fig. 5b), taken in 24 m water depth, shows continuous deposition from ice-proximal conditions to present nearshore sand with no indication of subaerial exposure. Another core (TUL97B045), in 28 m of water (Fig. 2), has a similar stratigraphy. Though this is far from conclusive, the indication in central Strait of Georgia along Vancouver Island is that relative sea level fell below present sometime between

11 and 10 ka BP to a maximum low stand of less than 20 m. This fits the predicted sea-level curve for this area (Clague et al., 1982).

DISCUSSION AND SUMMARY

The entire Strait of Georgia was overridden by ice during the Vashon Stade of the Fraser Glaciation leaving a till of variable thickness throughout most of the basin. Deglaciation appears to have been rapid with marine water incursion of most of the strait by 12.4 ka BP. Ice-distal glaciomarine deposition continued up until approximately 11.2 ka BP. However, there is no evidence of iceberg scours anywhere in the strait, suggesting that during deglaciation a retreating ice shelf producing icebergs was absent. Deglaciation appears, therefore, to have been quite rapid with regional downwasting and widespread stagnation. Sea level fell during deglaciation from a high stand that varied around the margins of the Strait of Georgia and continued to fall after all ice had left the strait, due primarily to isostatic adjustment. The data collected to date suggests that the ultimate low stand on eastern Vancouver Island could be less than 20 m below present-day sea level. However, this is based only on a few cores with little age control. The

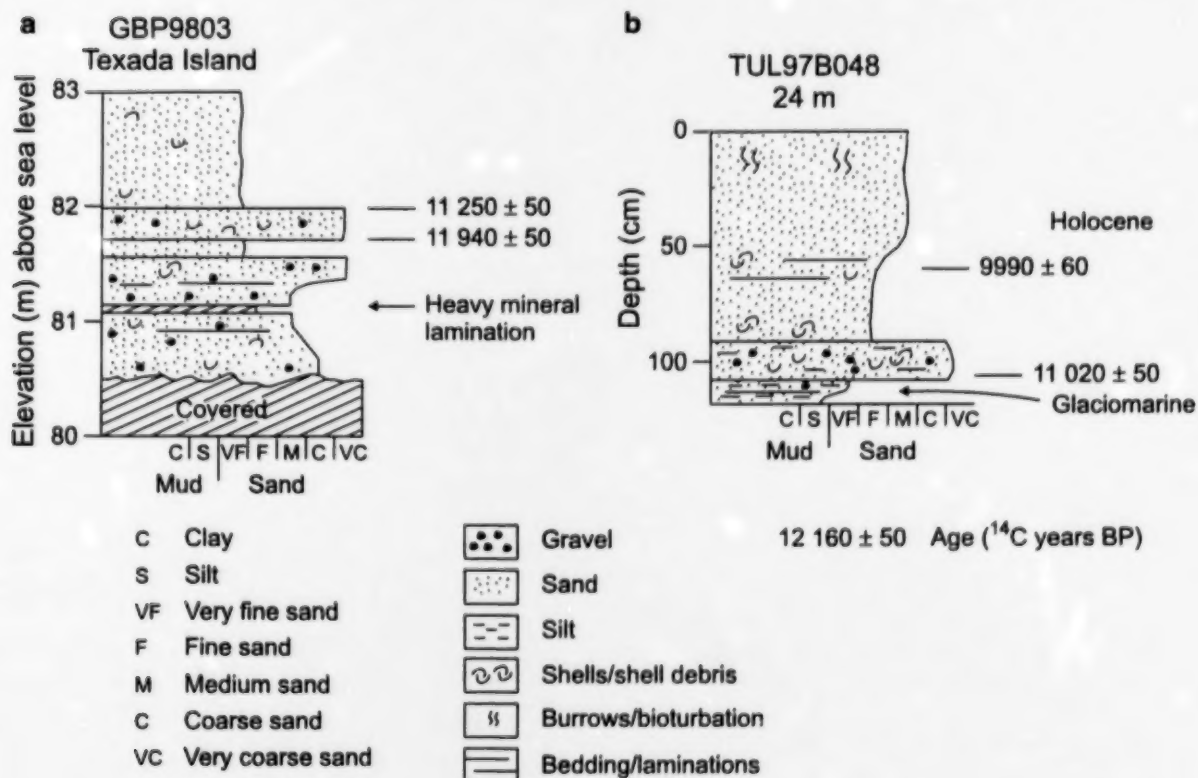


Figure 5. Stratigraphy and lithology of **a**) a raised beach section on western Texada Island and **b**) of a Holocene core recovered in a nearshore environment (24 m water depth) off Hornby Island. Location of the cores is shown in Figure 2.

timing and variation of the early Holocene relative sea-level low stand in the Strait of Georgia will be the focus of future research.

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